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# A Computational Cognitive Model Integrating Different Emotion Regulation Strategies

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**Abstract**
In this paper a cognitive model is introduced which integrates a model for emotion generation with models for three different emotion regulation strategies. Given a stressful situation, humans often apply multiple emotion regulation strategies. The presented computational model has been designed based on principles from recent neurological theories based on brain imaging, and psychological and emotion regulation theories. More specifically, the model involves emotion generation and integrates models for the emotion regulation strategies reappraisal, expressive suppression, and situation modification. The model was designed as a dynamical system. Simulation experiments are reported showing the role of the emotion regulation strategies. The simulation results show how a potential stressful situation in principle could lead to emotional strain and how this can be avoided by applying the emotion regulation strategies decreasing the stressful effects.

*Keywords:* Emotional Modeling; Cognitive Modeling of Agents; Cognitive Architectures

## 1 Introduction

Emotions are a crucial part of our mental activities and can play an important role in how we think and behave. Emotions provide the strong feelings and driving forces behind motivation (Gaulin and McBurney, 2004) depending on one's circumstances, mood or relationships with others. Emotions seem to rule our daily lives, we make decisions based on whether we feel happy, angry, sad, bored or frustrated, and emotions themselves have an adaptive potential that if activated can help a person change or avoid problematic states or unwanted experiences. Early research describes emotions as a neural activation states without a function (Hebb, 2005); later literature describes how emotions have various functions (Damasio, 2000; Oatley and Johnson-Laird, 1987). For instance, they facilitate decision making, prepare motor responses, provide information regarding the ongoing match between organism and environment, and script our social behavior (Gross, 1998; Schwarz and Clore, 1983). From the negative side, it has been found that recurring events triggering stressful emotions have a bad

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influence over time on psychological and physiological health and can easily lead to depression when subjects are vulnerable for that (Kessler, 1997).

Earlier, in the field of computational cognitive modeling, emotions were not considered for cognitive models, as they were assumed irrelevant for idealized cognitive functioning. However, in view of the increased awareness that emotions play a vital role in human life, nowadays cognitive models are being developed that include the generation (and sometimes regulation) of emotions as well. Over past two decades the research on emotions has increased significantly in various fields such as psychology and neuroscience, but also in the AI-related areas of virtual agents and ambient intelligence. In addition to the theories that exist in Psychology, also in Cognitive and Affective Neuroscience many contributions (Damasio, 2000; Dörfel et al., 2014; Schwarz and Clore, 1983) can be found about the relation between emotion and brain functioning. For example, emotional responses relate to activations in the brain within the limbic centers (generating emotions), and cortical centers (regulating emotions) (Dalgleish, 2004; Papez, 1937). Psychological research on emotions has started to focus more on emotion regulation (Gross, 2001, 1998; Gross and Thompson, 2007) i.e., the processes humans undertake to increase, maintain or decrease their emotional response.

In this paper, a computational cognitive model is presented that involves different emotion regulation strategies to gradually regulate the effect of negative events. It integrates the emotional responses on stressful events and the strategies that humans use to regulate them. The model integrates an existing model for emotion generation and regulation by reappraisal (Abro et al., 2014), with models for three different emotion regulation strategies as put forward by Gross (Gross, 2001; Gross and Barrett, 2011; Gross and Thompson, 2007). The model adopts part of previous work presented in (Abro et al., 2014), where only the reappraisal strategy was addressed. In the current paper this strategy is integrated with other strategies, namely expressive suppression and situation modification. Another approach to such integration of emotion regulation strategies can be found in (Bosse, Pontier and Treur, 2007, 2010); see also (Bosse, Gratch, Hoorn, Portier, and Siddiqui, 2010) for a comparative perspective. The model described in (Bosse, Pontier and Treur, 2007, 2010) is based on a cybernetical view, taking a notion of homeostasis as a point of departure, where every deviation from an assumed norm value for the emotion level triggers an adjustment, thereby using all strategies. In this sense the latter model is a kind of abstract black box model, as it does not use more specific inspiration from the biological and neurological area. The integrated model proposed in the current paper focuses on this biological inspiration and uses different and more neurologically plausible mechanisms based on that inspiration. An explanation about the different processes involved in emotion generation and regulation are discussed from such a perspective in Section 3. In the current model the three emotion regulation strategies are the antecedent-focused strategies reappraisal and situation modification, and the response-focused strategy expressive suppression. It is shown how these multiple processes of emotion regulation together can help people to maintain a healthy lifestyle in case the occurrence of stressful events.

The paper is organized as follows. First, in Section II some background information about the different processes of emotion regulation is presented. In Section III the integrated computational model is explained in detail. In Section IV simulation results are provided to show the influence of stressful events in a specific scenario, thereby providing evidence for the validity of the model. Finally, Section V concludes the paper.

# 2 Background

Emotions are instantaneous and specific reactions to a particular event that are usually of fairly short duration. Emotion regulation describes how a subject can use specific strategies to affect the emotion response levels (Cuijpers et al., 2007). Emotion regulation becomes more important when emotional responses interfere with important goals, or when they compete with other, socially more adequate responses (Côté et al., 2010; Koole, 2009). There is a variety of strategies to regulate emotions efficiently, which are used in daily life and that have been investigated within the areas of Cognitive, Affective, and Social Neuroscience. The term emotion regulation refers to those processes that affect the generation, the experience and expression of emotions. Emotion regulation depends on efficient cognitive control functions that are able to generate, maintain and adjust emotional responses (Egner, 2008), and realize different strategies.

Emotion regulation within individuals plays an important role in their life (Oatley and Johnson-Laird, 1987). Through their emotion regulation processes individuals can balance their emotions by exerting forms of control on how they feel (Gross, 2001). For instance, by avoiding situations or persons who trigger negative emotions, or suppressing anger when receiving bad comments from interviewers. By such emotion regulation mechanisms, persons have the ability to suppress negative influences from interaction with others and maintain a form of emotional homeostasis (Gross, 2001, 1998).

Humans use a number of strategies to affect their level of emotion response for a given type of emotion, for example, to avoid a too high or too low emotion response level. Emotions can be regulated or controlled in the different stages of the emotion generation process. Some strategies occur relatively early on in the emotion generation process and other, behavior regulated strategies happen relatively late in the emotion generation process (Gross, 2001; Gross and Thompson, 2007).

Gross (Gross, 1998) proposed an important theoretical framework that describes how individuals regulate emotions they have, when they have them and how they experience and express them. According to this emotion regulation framework there are two major categories of emotion regulation strategies: the first category concerns strategies that are used before an emotion has an effect on the behavior (antecedent-focused strategies) and the second category concerns strategies that are used when the emotional response is already coming into effect in the sense of expression or behavior after an emotion is generated (response-focused strategy) (Gross, 2002; Gross and Barrett, 2011; Gross and Thompson, 2007).

The proposed model integrates three different emotion regulation strategies: (1) reinterpretation. (2) expressive suppression and (3) situation modification (Gross, 2002, 1998).

Reinterpretation is a cognitive reappraisal mechanism, which works by changing the assigned meaning or interpretation of an emotional stimulus. Cognitive reappraisal is a form of cognitive change that involves construing a potentially emotion-eliciting situation in a way that changes its emotional impact (Lazarus and Alfert, 1964). Reappraisal is a specific type of cognitive change, which is aimed at down-regulating emotion, in the sense that the individual reappraises or cognitively re-evaluates a potentially emotion-eliciting situation in terms that decreases its emotional impact. An example of reappraisal is a case when a person loses a tennis match and blames the weather circumstances, instead of his own capacities.

Expressive suppression modifies the behavioral or physiological response to an emotional stimulus. Expressive suppression is a form of response modulation that involves inhibiting ongoing emotion-expressive behavior (Gross, 1998). For example, one might keep a poker face while holding a great hand during a card game. Response modulation, is a response-focused strategy, that is applied after the emotion response tendencies have been generated: a person tries to affect the process of response tendencies becoming a behavioral response. Expressive suppression is a specific type of response modulation, aimed at down-regulating emotion, that an individual inhibits ongoing expressive behavior (Gross, 2001). An example of suppression is a person that hides being nervous when giving a presentation.

Finally, situation modification (Gross, 1998) is an antecedent-focused regulation strategy that addresses the very first part of the causal chain from trigger to emotion, namely the external trigger itself. This is performed by preparing and performing an action that changes the external situation in such a way that the trigger disappears or becomes more harmless. A possible example of a situation modification is to run away from a potential unwanted situation.

In recent years more neurological mechanism have been discovered that describe the common and differential neural networks of emotion. According to the recent neurological fMRI study by (Dörfel et al., 2014) describes that what they call expressive suppression relates to an increase of brain activation in a right prefronto-parietal regulation network, and reinterpretation (reappraisal) engages a different control network comprising left ventrolateral prefrontal cortex and orbitofrontal.

The model presented here is inspired by a number of neurological theories (Dörfel et al., 2014; Kim et al., 2011; Phelps et al., 2004), relating to fMRI experiments in which it has been found that roughly spoken emotion regulation occurs through the interaction between prefrontal cortex and amygdala. For example, it has been found that less interaction or weak connections between amygdala and prefrontal cortex lead to less adequate emotion regulation (Koole, 2009).

The general idea is that upward interaction from amygdala to PFC can have the function of monitoring and assessing the level of emotion, whereas the downward interaction from PFC to amygdala makes it possible to control and modify amygdala activation. In the process of monitoring and assessing the level of emotion, leading to PFC activity, interaction with amygdala will occur and possibly with some other areas that also play a role in developing emotions and feelings. In relation to the control at the level of the PFC and connections from there to other areas some differentiation is needed. For different regulation strategies different areas need to be affected. For a response-focused strategy such as expressive suppression, a main effect can be to suppress amygdala activation in a more direct manner, but also other areas involved in actual expression of the emotion have to be suppressed, for example, keeping the poker face unmoved. Furthermore, for an antecedent-focused strategy such as reinterpretation it is quite plausible that in this case the control from the PFC has to affect the interpretation, and not the amygdala in a more direct manner. For example, in this case the PFC may affect (working) memory in order to achieve the reinterpretation. After this reinterpretation has been accomplished, in turn the renewed emotion generation process (based on the new interpretation) will affect the emotion level, including amygdala activity. In such a case a more direct suppression of amygdala activation might still take place as well, but then that effect may have to be attributed to a different regulation strategy which occurs in parallel, for example, expressive suppression. So, for a reinterpretation strategy the more important control effect should address the interpretation; in order to qualify the strategy as reinterpretation, the interpretation has to change, which requires some specific effort. Without an important contribution of the latter control effect the type of regulation would probably have to be classified as response-focused and not as reinterpretation. Similarly, for an antecedent-focused strategy such as situation modification, the control has to address primarily not the amygdala, but, for example, different areas involved in executive planning of actions to get the situation modified, which also may require quite some effort. Also here it is plausible that the control effect from the PFC addresses mainly areas different from the amygdala in order to achieve a modified situation, and in turn the amygdala activation gets affected due to the renewed emotion generation process based on the modified situation. Again, without this modified situation the strategy would not be classified as situation modification.

To control different pathways in order to achieve emotion regulation according to different strategies the PFC has to involve different areas within the brain. In some recent studies such as (Ochsner and Gross, 2014; Dörfel et al., 2014) some first attempts are made to relate different regulation strategies to activity in different brain areas. See, for example, (Ochsner and Gross, 2014, pp. 30-33). As another example, see (Dörfel et al., 2014) which describes that what they call expressive suppression relates to an increase of brain activation in a right prefronto-parietal regulation network, and reinterpretation engages a different control network comprising left ventrolateral cortex and orbitofrontal prefrontal. More studies are needed in this area to obtain more solid conclusions on the differences between different strategies.

# 3 Cognitive Model

In this section, the focus is on different parts and states of the proposed model, and it is explained how the different states affect each other. An overview of the proposed model is depicted in Fig. 1, with an explanation of the terms used in Table 1. A short description of each state is available in Table 1. All states of this model can be classified in five groups: the outside environment, emotion generation, and emotion regulation strategy 1, 2 and 3.

## 3.1 Environment

The main states representing the outside environment are world event and world. Here world(w) shows the situation of the person's environment (how suitable, annoying is it). Moreover, world(e) covers the events (external to the person) which may affect the environment for the person.

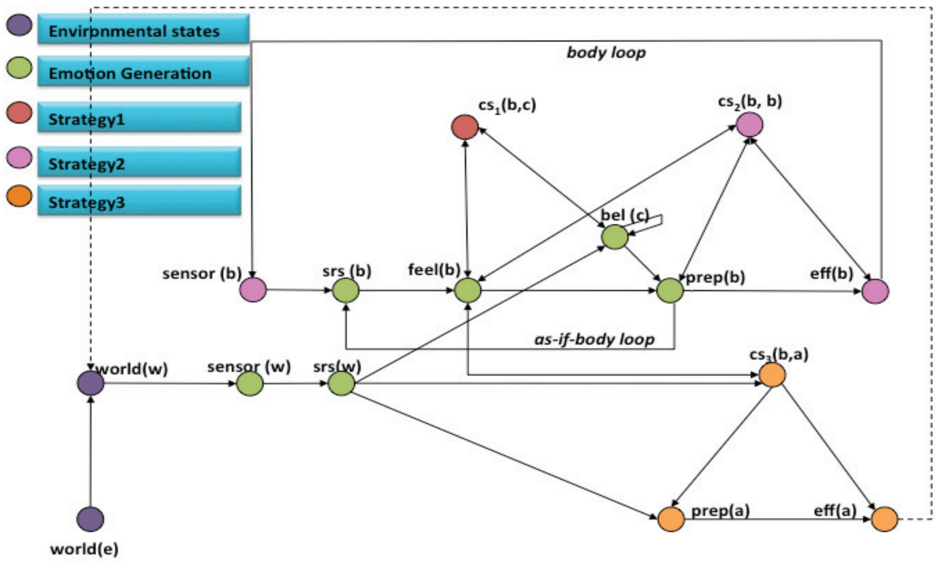


**Figure 1:** Proposed Model. States belonging to the same group are colored in the same color

## 3.2 Emotion Generation

The state of the world is sensed by the person via sensor(w)) and represented as srs(w). This is associated both to a positive belief bel(c1) and a negative belief bel(c2), which form a basis of two different interpretations of the same world condition. As discussed earlier, these conflicting beliefs compete with each other by a form of mutual inhibition. In the considered scenario, the negative belief bel(c1) has an effect on the state of preparation for negative emotional response prep(b) which leads to sensory representation srs(b) and to the negative feeling feel(b). Subsequently, feel(b) has an impact on the preparation state, prep(b), which in turn has an impact on feeling state, feel(b), through srs(b) which makes the process recursive; this is often called an as-if body loop in the literature (e.g.

| Domain | Formal name | Informal name | Description |
|---|---|---|---|
| Environment | world(w) | World state w | This characterizes the current world situation which the person is facing |
| | world(e) | World event e | Circumstances in the world that affect the world situation in a stressful manner (e.g., loosing your job, or a noisy place) |
| Emotion Generation | sensor(w) | Sensor state for w | The person observes the world state through the sensor state, which provides sensory input |
| | srs(w) | Sensory representation of world state w | Internal representation of sensory input |
| | srs(b) | Sensory representation of body state b | Before performing an action, a feeling state feel(b) for the action is affected by a predictive as-if body loop, via the sensory representation state srs(b). This gives a sense of valuing of a prediction about the action before executing an action to perform it. Here b is embodying the associated emotion. In the considered scenarios b is a negative emotion |
| | feel(b) | Feeling associated to body state b | |
| | bel(c) | Belief c | Interpretation of the world information; in the case of different interpretations for the same world information, they may suppress each other |
| | prep(b) | Preparation for an action involving b | Preparation for a response involving body state b |
| Emotion Regulation Strategy 1 | **Reappraisal** Re-interpretation of world information by belief change; this works by changing the assigned meaning to a stimulus with negative emotional effects. For example, after losing a match, a person can reinterpret the situation, by believing that the rival was exceptionally powerful. | | |
| | cs1(b,c) | Control state of reappraisal of belief c to avoid feeling b (first regulation strategy) | This control state is monitoring beliefs and associated feelings, to determine whether an unwanted, negative emotion through a belief has occurred. If so, by becoming activated the control state suppresses this belief, which gives the opportunity for alternative beliefs to become dominant. |
| Emotion Regulation Strategy 2 | **Suppression of emotion-expressive behavior** For example, hide one's true feelings from another person, like hiding one's fear when standing up to a bully | | |
| | cs2(b, b) | Control state of expressive suppression of b to avoid feeling b (second regulation strategy) | This control state monitors feelings and preparation for b, to determine whether an unwanted, negative emotion has occurred. If so, by becoming activated the control state suppresses the effector state for b. |
| | sensor(b) | Sensing body state b | The person keeps track of his or her body states (maintaining body representation in the brain). |
| | eff(b) | Effector state for body state b | Body expression of b, for example a fear expression (e.g., by putting the face in a certain expression) |
| Emotion Regulation Strategy 3 | **Situation modification** For this strategy the person performs an action in the external world to change a situation which triggers negative emotions into a better one. For example, walking away from a noisy place and enter a quiet place. | | |
| | cs3(b, a) | Control state of situation modification action a to avoid feeling b (third regulation strategy) | This control state monitors feelings and sensor representation of the world situation, to determine whether a situation is unwanted. If so, by becoming activated the control state activates the preparation and execution of action a to change this situation. |
| | prep(a) | Preparation for action a | Preparation to modify the situation by action a |
| | eff(a) | Effector state for action a | In the considered scenarios the action a is changing the situation by decreasing the level of world state w |

**Table 1:** Overview of the states of the proposed model (see also Figure 1)

(Damasio, 2000)). Other states, depicted in Fig. 1, are control states related to three emotion regulation strategies, which are described below. These control states monitor and control a number of states in order to regulate bad emotions in different ways.

## 3.3 First Emotion Regulation Strategy: Reappraisal

As described in Section 2, emotions can be controlled in different phases of the process during which emotions are generated. The first strategy discussed is focused on changing the bad beliefs about the situation into more positive ones. This provides reinterpretation of the world information. Therefore, when the person has generated a specific dominant belief bel(c2) which associates to bad feelings feel(b), this belief and the negative feelings lead to the activation of the control state cs1(b, c), and consequently this control state weakens the belief bel(c2) and due to this the positive belief bel(c1) can become dominant, which provides an alternative interpretation of the world.

## 3.4 Second Regulation Strategy: Expressive Suppression

This strategy concerns a response-focused emotion regulation mechanism, which suppresses the emotion response (suppressing means that an individual inhibits ongoing expressive behaviours (Gross, 2001)) without taking away or modulating the triggers for this response. In this strategy, the person tries to control his or her feeling by not expressing it. Expressing a poker face or fighting against tears are examples of this mechanism. In contrast to the other emotion regulation strategies, this strategy (also called response modulation) occurs late in the emotion generation process, after response tendencies have been initiated (Gross and Thompson, 2007). Response modulation refers to influencing physiological, experiential, or behavioral responding as directly as possible. Attempts at regulating the physiological and experiential aspects of emotion are common. Drugs may be used to target physiological responses such as muscle tension (anxiolytics) or sympathetic hyper-reactivity (beta blockers).

Exercise and relaxation also can be used to decrease physiological and experiential aspects of negative emotions. In the model the control state cs2(b, b) of this strategy is activated when an unwanted emotion is monitored in feel(b) and prep(b), and suppresses the expression of the emotional response eff(b). This eff(b) is sensed by the person him or herself through the body loop, and through that it strengthens the emotion level; getting rid of it or weakening it will have a decreasing effect on the emotion level.

## 3.5 Third Regulation Strategy: Situation Modification

The third emotion regulation strategy considered is situation modification. Leaving an annoying place or person is an example of this strategy. In the model the control state for this kind of emotion regulation cs3(b, a) is affected by sensing a situation or stimulus via srs(w) and a bad feeling feel(b) associated to it. Its activation leads to preparing and performing an action a (i.e., prep(a) and eff(a)) which can change the situation (characterized by world(w)), for example walking away from a noisy place to a quite place.

The model is conceptually represented as a collection of states and the connections among those, as described above. Numerically the states have activation values (real numbers between 0 and 1) over time where also the time variable is assigned real numbers. A state has different values at various time points, any new updated particular value is generated at each point in time. The update mechanism of a state from time point t to time point t + $\Delta$t depends on all the incoming connections to that state. There are few things which are worth noting here. It makes use of a combination function based on the logistic threshold function:

$$\text{th}(\sigma, \tau, X) = (1/(1+ e^{-\sigma(X-\tau)}) - 1/(1+ e^{\sigma\tau})) (1+ e^{-\sigma\tau}) \quad (1)$$

The role of threshold function is in the process of aggregating all the incoming impact from other states to the considered state into one impact which is in the interval [0, 1]. For example, for the state feel the model is numerically represented as

$$\text{agg\_imp\_feel}(t) = \omega_{srs,feel}\ \text{srs\_b}(t) + \omega_{cs1,feel}\ \text{cs1}(t) + \omega_{cs2,feel}\ \text{cs2}(t) + \omega_{cs3,feel}\ \text{cs3}(t) \quad (2)$$

$$\text{imp\_feel}(t) = \text{th}(\sigma, \tau, \text{agg\_imp\_feel}(t))$$

$$\text{feel}(t + \Delta t) = \text{feel}(t) + \eta_1\ (\text{imp\_feel}(t) - \text{feel}(t))\ \Delta t \quad (3)$$

Note that agg_imp_feel(t) does not need to stay in the interval [0, 1]. However, the threshold function th(σ, τ, X) maps it to imp_feel(t) which is in the interval [0, 1].

In this way the model illustrated conceptually in Figure. 1 is becoming a computational numerical model in terms of difference or differential equations. The simulations are performed with this numerical model. All states and differential equations for them have been converted in a form which can be computed in a programming environment. All the simulations are performed within the MATLAB™ environment.

# 4 Simulation Experiments and Results

A number of simulation experiments have been conducted according to different scenarios. The simulation was executed for 130 time steps with $\Delta t = 0.1$. Parameter values of weights for connections between all states are provided in Table 2. Values for parameters threshold τ, steepness σ, and update speed η are given in Table 3. These values have been obtained by considering the patterns that are known from literature and searching for the ranges of parameter values that provide such patterns. The initial values for all states were set to zero.

| ω (weight) | value | | ω (weight) | value |
|---|---|---|---|---|
| $\omega_{eff(a),world(w)}$ | -1 | | $\omega_{cs1,feel}$ | -0.1 |
| $\omega_{world(w),ss(w)}$ | 1 | | $\omega_{cs2,feel}$ | -0.2 |
| $\omega_{ss(w),srs(w)}$ | 1 | | $\omega_{cs3,feel}$ | -0.3 |
| $\omega_{srs(w),bel1}$ | 0.4 | | $\omega_{bel2,prep(b)}$ | 0.9 |
| $\omega_{cs1,bel1}$ | 0.0 | | $\omega_{feel,prep(b)}$ | 0.4 |
| $\omega_{bel2,bel1}$ | -0.3 | | $\omega_{cs2,prep(b)}$ | -0.2 |
| $\omega_{srs(w),bel2}$ | 0.9 | | $\omega_{prep(b),srs(b)}$ | 0.9 |
| $\omega_{cs1,bel2}$ | -0.25 | | $\omega_{ss(b),srs(b)}$ | 0.5 |
| $\omega_{bel1,bel2}$ | -0.3 | | $\omega_{prep(b),eff(b)}$ | 1 |
| $\omega_{feel,cs1}$ | 3 | | $\omega_{cs2,eff(b)}$ | -0.1 |
| $\omega_{bel2,cs1}$ | 1 | | $\omega_{eff(b),ss(b)}$ | 1 |
| $\omega_{bel1,cs1}$ | 0.0 | | $\omega_{feel,cs2}$ | 0.1 |
| $\omega_{srs(b),feel}$ | 0.9 | | $\omega_{prep(b),cs2}$ | 0.8 |
| $\omega_{eff(b),cs2}$ | 0.8 | | $\omega_{cs3,eff(a)}$ | 0.8 |
| $\omega_{srs(w),prep(a)}$ | 0.1 | | $\omega_{prep(a),eff(a)}$ | 0.7 |
| $\omega_{cs3,prep(a)}$ | 1 | | $\omega_{srs(w),cs3}$ | 0.8 |
| $\omega_{feel,cs3}$ | 0.3 | | | |

**Table 2:** Values for the connection weight parameters

| | τ | σ | η |
|---|---|---|---|
| **prep(b)** | 0.4 | 4 | 6 |
| **feel** | 0.1 | 5 | 6 |
| **bel1** | 0.1 | 9 | 6 |
| **bel2** | 0.43 | 9 | 6 |
| **cs1** | 0.9 | 15 | 0.5 |
| **srs(b)** | 0.2 | 3 | 6 |
| **eff(b)** | 0.5 | 4 | 6 |
| **cs2** | 0.05 | 5 | 6 |
| **ss(b)** | 0.5 | 4 | 6 |
| **ws** | 0.1 | 5 | 0.4 |
| **ss(w)** | 0.4 | 5 | 6 |
| **srs(w)** | 0.4 | 5 | 6 |
| **prep(a)** | 0.4 | 5 | 6 |
| **eff(a)** | 0.5 | 100 | 6 |
| **cs3** | 0.4 | 5 | 0.1 |

**Table 3:** Values for parameters τ, σ and η

All processes run in parallel, so each regulation strategy can become activated right from the start. However, some strategies use mechanisms that are faster than other strategies, which leads to some emergent order of showing up: the faster strategies will occur earlier than the slower ones. For example, expressive suppression uses more direct mechanisms than strategies such as reinterpretation or situation modification. In the latter two cases first some work has to be done (on the interpretation or body movement to change a situation, respectively) before an effect on emotion level occurs. Moreover, if a fast strategy is already totally effective so that the emotion level is already reduced, then there may be no need anymore for the other strategies to become active. So, both the occurrence of strategies and their timing are emergent processes. Given this, typically a simulation experiment will show how some of the three regulation strategies occur over time, in some emerging order, depending on the time the respective processes take. Given the timing of the processes, in the experiments described below the first control state that activates is cs2(b, b) which suppresses the negative feelings. Next control state cs1(b, c) activates and further decreases the feeling by reinterpretation. The reason for control state cs1(b, c) to be slower is that a person tends to sticks to his/her belief for some time: it takes some time to change beliefs, which is longer compared to a direct suppression of feelings. Still later, control state cs3(b, a) activates which performs the situation modification by executing the action a. This is still slower as it involves physical movement, which usually takes more time than mental processes. The model makes it easy to create experiments in which different strategies occur with different timing by varying the timing of the different control states and other states involved. For instance it may be modelled that a specific person immediately runs away from a situation first and then still may or may not apply cognitive reappraisal and suppression to reduce the effects of a negative circumstance.

To describe the results in this section a hypothetical scenario is used. John Doe has few options to reward himself during the weekend break, and one of them is to watch a cricket match; his favorite team is performing very well in the championship. He joins friends to watch the match. The match is against a comparatively weak team. When the match has started his favorite team shows a fluctuating performance with sometimes good and sometimes bad actions. He starts to believe that the match may end up in a bad result, which triggers negative feelings. He suppresses these negative feelings. Moreover, he tries to lower his negative belief and feeling to give space for a positive belief and feeling (his team also has some good actions). However still some negative feeling remains. Therefore he decides to walk out of the stadium and watch a movie in a cinema instead.

The results are illustrated in Figure 2 and are as follows. Three different types of regulations are

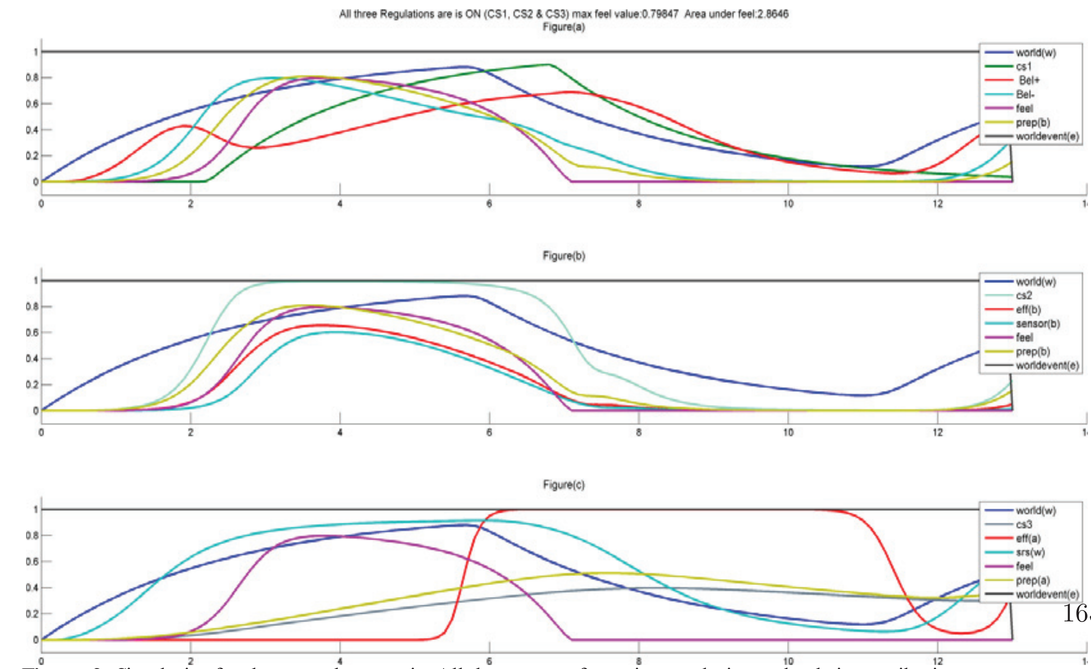


**Figure 2:** Simulation for the example scenario. All three types of emotion regulation make their contribution.

applied in the above scenario. Emotion regulation is modeled as a continuous process showing how three different emotion regulation strategies could take place simultaneously in a real life scenario. The simulations show they take place in a specific order, first emotion suppression (down-regulating negative feelings without altering the beliefs), emotion regulation by altering the beliefs, and situation modification if an individual is not satisfied with the current situation. As the simulation starts, in the beginning control state cs2(b, b) (depicted in aqua marine) activates, which acts as a suppressor to the negative feeling (showed in magenta in graph (b)), as it can be seen in graph (b) the feeling reaches its maximum activation level 0.79 but then gradually goes downward because of the effect exerted by cs2(b, b).

The effect of cs2(b, b) on feeling is not yet strong enough, so here comes the role of control state cs1(b, c) (depicted in green color, in graph (a)) which helps by altering the beliefs and lowering the negative feeling further. Positive and negative beliefs are illustrated in graph (a) in red and light green color, respectively. Between time point 5 and 6 this switching of beliefs takes place and also the negative feeling is further decreased.

At the end control state cs3(b, a) (in gray color, graph (c)) activates which performs the type of regulation known as situation modification. In graph (c) it is illustrated that an effect where an individual thinks that the situation is not very happy with the situation and therefore the only solution is to run away, for instance as portrayed in the example scenario above. The pattern of eff(a) is almost binary. When eff(a) fully activates at time point 6, almost at the same time eff(b) deactivates.

Table 4 provides a summary of a large number of simulation experiments that have been performed. The first column includes the regulation strategies, which are involved in different cases for example in case 5 only situation modification is used. Parameters values for different connection weights used during regulation processes are mentioned in rows colored in blue, orange, and green for example parameters from belief 2 and feel to CS1 $\omega_{bel2,cs1}$ and $\omega_{feel,cs1}$ are used for reappraisal. Rows with red color show the feeling intensity and maximum feeling values. Feeling Intensity is computed as the area under the feeling curve for instance when all regulation strategies are active it is "2.8646". Last three rows contains the information about whether a feeling decreases, a belief changes or situation is changed with regard to three different emotion regulation strategies for instance in "case 4" two regulation strategies are used reappraisal and emotion suppression.

| Regulation Scenario / States | Case1 | Case 2 | Case 3 | Case 4 | Case 5 | Case 6 | Case 7 | Case 8 |
|---|---|---|---|---|---|---|---|---|
| **Reappraisal** | No | Yes | No | Yes | No | Yes | No | Yes |
| **Suppression** | No | No | Yes | Yes | No | No | Yes | Yes |
| **Situation Modification** | No | No | No | No | Yes | Yes | Yes | Yes |
| $\omega_{bel2,cs1}$ | 0.0 | 1 | 0.0 | 1 | 0.0 | 1 | 0.0 | 1 |
| $\omega_{feel,cs1}$ | 0.0 | 3 | 0.0 | 3 | 0.0 | 3 | 0.0 | 3 |
| $\omega_{feel,\ cs2}$ | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.1 | 0.1 |
| $\omega_{prep(b),\ cs2}$ | 0.0 | 0.0 | 0.8 | 0.8 | 0.0 | 0.0 | 0.8 | 0.8 |
| $\omega_{eff(b),cs2}$ | 0.0 | 0.0 | 0.8 | 0.8 | 0.0 | 0.0 | 0.8 | 0.8 |
| $\omega_{feel,cs3}$ | 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.3 | 0.3 | 0.3 |
| $\omega_{srs(w),cs3}$ | 0.0 | 0.0 | 0.0 | 0.0 | 0.8 | 0.8 | 0.8 | 0.8 |
| **Feeling Intensity** | 10.3452 | 9.9384 | 9.2812 | 5.3516 | 7.2597 | 5.2699 | 5.2732 | 2.8646 |
| **Feeling (max value)** | 0.96173 | 0.94779 | 0.89185 | 0.83758 | 0.9516 | 0.93669 | 0.858 | 0.79847 |
| **Feeling decreasing?** | No | No | No | Oscillation (lower level) | Yes | Yes | Yes | Yes |
| **Beliefs switch?** | No | Yes | No | Yes | No | Yes | No | Yes |
| **Situation change?** | No | No | No | No | Yes | Yes | Yes | Yes |

**Table 3:** Summary of results with respect to different scenarios

It is observed that in relation to these two strategies whether feelings and beliefs are effected which in this case shows (last three rows) that beliefs are changed and feelings have oscillation effect. Although feelings do not decrease completely but even oscillation is at lower level as compare to initial maximum level.

# 5 Conclusion

In this paper a model was presented to simulate the integration of different emotion regulation strategies. As emotions play an important role in daily life, regulating them is an integral part of dealing with emotions. To maintain a healthy and, for example, depression free lifestyle, understanding the basis of emotion generation and regulation processes is essential. In this paper a dynamical model for the integration of three types of emotion regulation strategies is discussed, namely (a) Reappraisal, (b) Suppression (d) Situation Modification. The model was analysed through simulations experiments for a variety of specific scenarios.

The model reflects that emotion regulation is a continuous process, an individual/agent capable of using emotion regulation effectively can use different strategies over a course of time in a given situation. The results show that indeed this process of continuous emotion regulation by applying different strategies suitable to a particular circumstance in a stressful situation can be achieved computationally.

The kind of computational model proposed in the paper can be embedded in a virtual agent or avatar and used to train a human to deal with potential stressful events. One of the possible extensions to the model is to incorporate contagion effects of stress in a social network environment. Another extension is possible learning of emotion regulation behavior. Future work would also include some psychophysics experiments and empirical validation of the model.

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